QUALITY FUNCTION DEPLOYMENT FOR LARGE SYSTEMS

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Abstract : Quality Function Deployment (QFD) is typically applied to small subsystems. This paper describes efforts to extend QFD to large scale systems. It links QFD to the system engineering process, the concurrent engineering process, the robust design process, and the costing process. The effect is to generate a tightly linked project management process of high dimensionality which flushes out issues early to provide a high quality, low cost, and, hence, competitive product. A pre-QFD matrix linking customers to customer desires is described.

BACKGROUND

Upon being asked to give the introductory lecture at the National Aeronautics and Space Administration Advanced Project Management Course in October 1991, I undertook the challenge to present new approaches to project management which would be similar to, yet different from, current approaches. This led to the framework in which the concepts in this paper are embedded.

Why new ways of project management? Because of performance increases, the first unit cost of large systems in the United States for many years has been escalating at about 2.9% per year above inflation [1]. Augustine noted this trend in the 1970's [2]. Others have examined, quantified, and applied this phenomena [3-8].

Could this trend be changed? Although the size of systems has increased, size could not explain the escalation. The other primary cost parameter is complexity, the natural logarithm of the cost of the first pound of the first production unit. Complexity has two components: the complexity of the system and the the complexity of the system to bring forth the system. Since requirements and technology largely dictate the complexity of the system, analysis was focused on the complexity to bring forth the system.

Various techniques were identified, including QFD, which tend to reduce cost [9-11]. Attempts to apply QFD within the NASA system environment led to the need to modify QFD when applied to large systems. Simple changes in terminology, such as using "subsystems" for "parts," led to direct analogies with the system engineering process [12]. The embedding of QFD within the system engineering process follows.

QUALITY FUNCTION DEPLOYMENT AND EXTENSIONS

QFD was developed to design quality into a product [11]. QFD utilizes basic dimensionality within a project to provide a structured way of designing quality into a system. It addresses dimensions including customer desire, quality characteristics, functions, parts, and failure modes.

A customer desire is the quality demanded by the customer. A quality characteristic is a measurable attribute by which one can measure whether a customer is getting the demanded quality. A function is something the system must do to ensure the demanded quality. A function is defined here in the form <verb,noun> [13]. Quality characteristics and system functions intersect, as shown in Figure 1, to define a requirement variable of the form <function,attribute> which is equated to a constant to define a requirement [13]. Requirement variables can be fixed to create requirements or they can be used as design guidelines for improving the system.

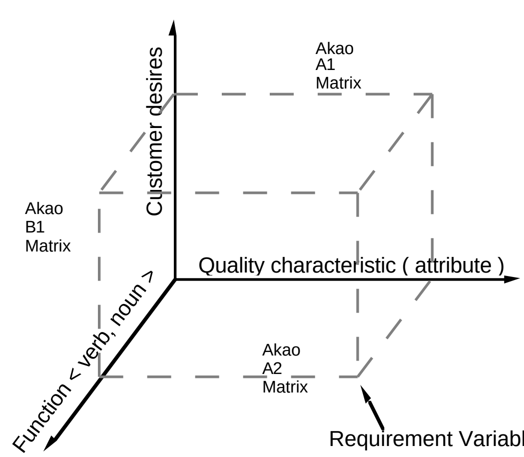

Figure 1: Requirement Definition

In QFD, each customer desire is given a value. Quality characteristics are defined through brainstorming to generate an affinity diagram. After forming a tree diagram of the chosen quality characteristics, those at the lowest level are placed on the axis of a matrix. The customer desires are placed on the other axis. Each quality characteristic is compared with each customer desire to determine if there is no correlation (value = 0), a weak correlation (value = 1), a moderate correlation (value = 3), or a strong correlation (value = 5 (Japan) or 9 (America)). The dot product of the customer desire values and the correlations for a specific quality characteristic provide a value for that quality characteristic. This may be interpreted as the value of a quality characteristic for a specific customer desire valuation. Mathematically speaking, the vector of values of customer desire is transformed to a vector of values for quality characteristics using the customer desire/quality characteristic correlation matrix. The same process is used to identify functions, correlate them with customer desires, and transform customer desire values to function values using the customer desire/ function correlation matrix.

Quality characteristics and functions can be ranked in terms of transformed customer value to determine which are the most important. This can be used for task prioritization. If resources are constrained, then most priority can be given to those with the highest customer value.

Since QFD was developed to design quality into small systems such as car doors and rear view mirrors, it has historically not been applied to large systems. Application to large systems requires tailoring [9]. For example, the concept of "part" must be extended to "subsystem". It is also more meaningful to view QFD as a process to define a system which must meet demanded quality. This is a subtle but important distinction. It leads to the definition of functions prior to the definition of quality characteristics and to the definition of quality characteristics in relation to functions which must be accomplished.

Going beyond QFD, the product of the function value, the quality characteristic value, and the function/quality characteristic correlation value can be used to prioritize requirement variables.

In keeping with the American system engineering process, as in Figure 2, functions are allocated to systems [12]. This can also be viewed as the allocation of requirements to subsystems in that a subsystem must meet a set of requirements.

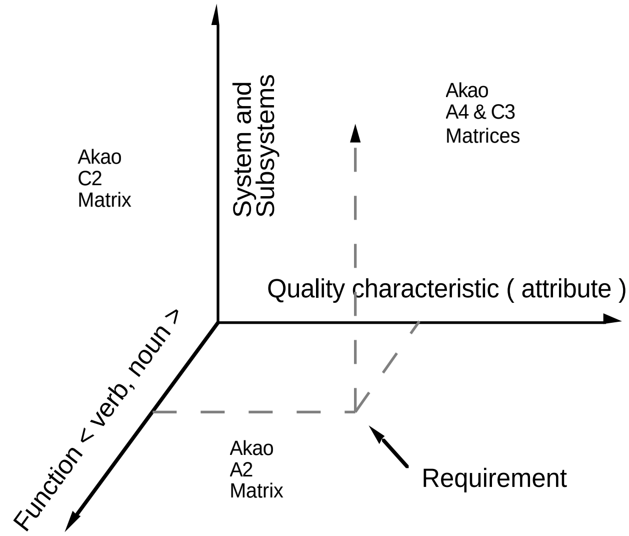

Figure 2: Allocating Requirements to Subsystems

Note that each requirement variable is a measurable attribute for which a correlation exists between the function and the quality characteristic. It is, thus, on the A2 plane that measurable quantities exist. If these variables can be related through equations, they provide a parametric behavioral description of the product.

As illustrated by Figure 3, customer desire values can also be transformed to new concept values through the customer desire/new concept correlation matrix and to failure mode values through the customer desire/failure mode correlation matrix. Concept trades can be performed as illustrated by Figure 4. Concepts become requirement/subsystem planes over which cost, schedule, and performance are evaluated. The evaluation may provide feedback for further requirements which may modify subsystems.

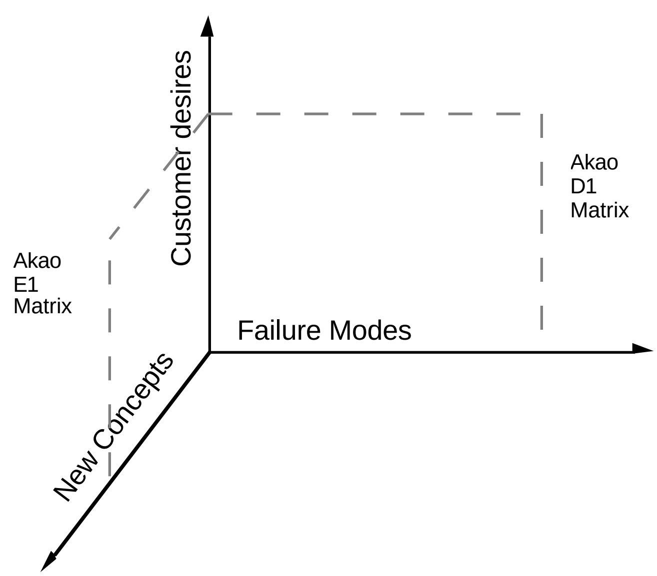

Figure 3: New Concepts and Failure Modes

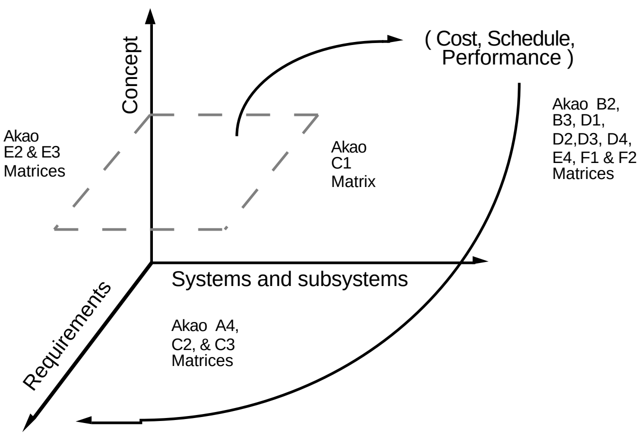

Figure 4: Concept trades

Our first application of QFD was to a proposed Lunar Rover. It uncovered the need to track demands from specific customers. The result, Figure 5, was a matrix of customers versus customer demands which could be iterated as the customer environment changed.

Because a large system within NASA has many customers, often with conflicting desires, we found the need to value each customer with respect to the need for the project to satisfy their desires. This quantifies customer political power. Because customer desires often conflict with the goals and needs of the project, we found the need to value each customer demand with respect to the goals of the project. The final value for a customer demand becomes the value to the project of the customer demand times the dot product of the value of the customer and the correlation between the customer and the customer demand.

Customer \ Desire/Demand	Value of Customer	High Quality	Low Cost	Short Schedule	High Performance	Politically Acceptable	Within Regulations	Alligns with Organization	Does X	Technology Spinoff	Customer Impact
Value to Project											
Sponsor											
Institution											
Administrator											
NASA											
Congress											
Taxpayer											
Regulatory Agencies											
Users											
Value of Demand											

● Strong Correlation ◉ Average Correlation ○ Weak Correlation

Figure 5: Customer Versus Customer Demand Matrix

Large projects have a large number of customer demands, functions, and quality characteristics. We found it necessary to threshold these based on transformed customer value. Choosing only the highest valued customer demands facilitates early system definition by reducing the time required to correlate each customer demand with each function and each quality characteristic. The thresholds can be lowered as the project proceeds to enable more of the system information base. Decreasing the customer demand threshold can generate a minor reordering of the ranking of functions, quality characteristics, and requirements.

Since we were using linked spreadsheets, we found it cumbersome to use the symbolic notations of correlation associated with QFD. We went directly to a numeric format.

CONCURRENT ENGINEERING

For large systems, expertise across many fields is required to define and rank the customer demands, functions, quality characteristics, systems, new concepts, failure modes, and associated correlation matrices. Thus, the need for concurrent engineering emerges.

> Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements [14].

A dimensionality not included within QFD, but which is related to it, is that of the project or life cycle functions required to implement the system functions in the system.

Figure 6 illustrates this. For each system, the life cycle or project functions are staffed with appropriate disciplines over time to operate on the phases of the project. Conceptual design of the support phase conceptualizes the support concept; design of the support phase finalizes this concept; development of the support phase provides a prototype support system; test and evaluation evaluates the prototype support system; production of the support phase provides the final support system; operation of the support system is the support of the system; support of the support phase includes the maintenance and supply of the support system; and retirement terminates all support activities and disposes of the support system.

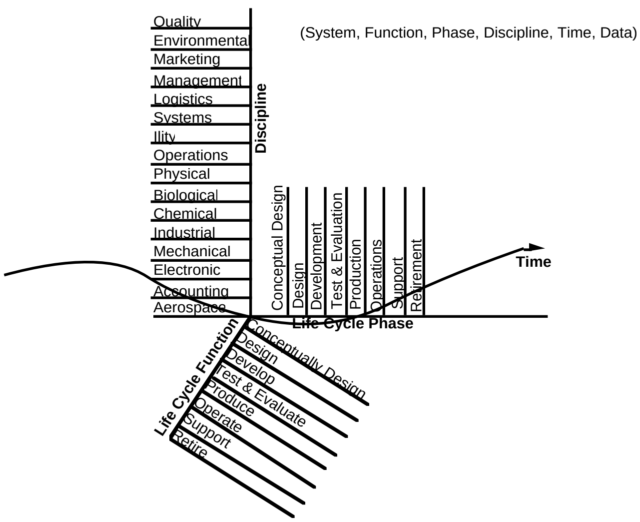

Figure 6: Concurrent Engineering Dimensionality

Because of the wide range of expertise required for large systems, it becomes evident that generalists are more desirable than specialists. Too many people in the room at one time become both uneconomical and unmanageable. This also leads to the need to decentralize by decomposing the system into meaningful subgroupings with low interaction. Fortunately, the geometric nature of QFD is a natural medium in which to perform that decomposition and manage the interaction.

ROBUST DESIGN

Robust design was developed by Taguchi [15]. It uses design of experiments to obtain a near optimal parameter setting for a subsystem with respect to specified quality characteristics such as reliability [16]. The function/quality characteristic plane contains measurable variables which are logical choices as either parameters or objectives for the robust design process.

As was QFD, robust design was developed for application to small subsystems and components during the design phase. Recent applications have demonstrated that it is equally applicable at the system level during the conceptual design phase for large systems [17-18]. It is, thus, a natural complement to QFD in the design of large systems.

COST MEASUREMENT

Activities associated with project functions are the source of the cost of the system. This leads to a natural cost structure illustrated by Figure 7. The cost categories may be defined as desired. Figure 8 intersects the more recent concept of activity based costing, the cost of the activities of the project functions, with the MIL STD 881 type of end item oriented subsystem work breakdown structure [19].

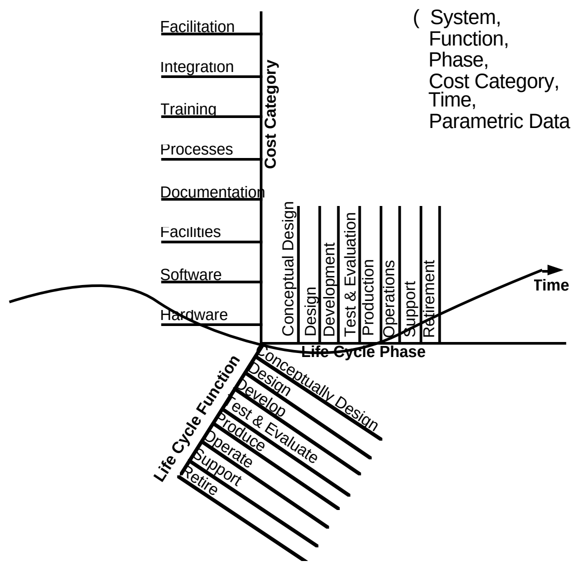

Figure 7: Life Cycle Cost Structure

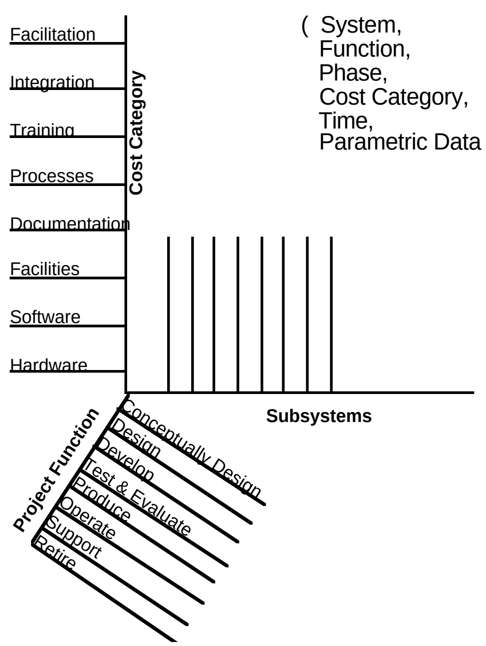

Figure 8: Activity Based vs. Subsystem Cost

CONCLUSIONS

With minor modifications, QFD is a system engineering process which can be applied to large systems. It can be extended to a project structure which also includes customers, project functions, project phases, project resource utilization, and other dimensions. Concurrent engineering is a natural component of the QFD process for large systems. The limited experience to date indicates that this form of extended QFD is an intensive group mental activity which is an excellent thought tool for defining complex systems. The observation that designing is largely defining indicates that QFD is a natural tool for the design process. Using linked spreadsheets to record results provides a powerful project knowledgebase which can be used for "what if", risk, and project sensitivity analyses.

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